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THE USABILITY OF HYDROGEL IN INCREASING THE EFFICIENCY OF GYPSUM APPLIED TO SALINE-SODIC SOILS

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Abstract: This study aimed at the assessment of the usability of hydrogel in increasing the efficiency of gypsum applied to saline-sodic soils. The experiment was conducted under laboratory conditions in disturbed soil columns and was set-up in a completely randomized design with six hydrogel application rates (Control, 0.05%, 0.10%, 0.15%, 0.20% and 0.25% weight/weight (*w/w*) basis) and with three replications. Hydrogel application to saline-sodic soil had significant effects on leachate pH. The highest leachate pH's were found in the final leachates in the order of 0.05%>0.10%>0.15%, as 9.12, 9.09, and 9.03, respectively. In all of the application rates tested, the highest electrical conductivity (EC) and Na^+ leachate losses were obtained after first pore volume of leaching and then decreased gradually with further leaching. Relative to the control, hydrogel application in the rate of 0.05% increased the leaching of Na^+ by 8.1% on total. However, due to the absence of statistically significant effects of the treatments on Na^+ leaching, an improvement in soil exchangeable sodium percentage (ESP) and pH in saturation extract (pH_e) values as an indicator of reclamation was not proven. Use of gypsum together with hydrogel increased saturated hydraulic conductivity of soils in the rates of 28.6%-42.6%, which is especially important for reducing the duration for amelioration of saline-sodic soils. Application of hydrogel to saline-sodic soils along with gypsum can be an efficient management option not only for reducing the risk of physiological drought, but also for reducing the amount of time to reclaim saline-sodic soils.

Keywords: Gypsum, hydrogel, reclamation, saline-sodic soil

1. INTRODUCTION

Agricultural land is a limited resource and cannot be recovered within the life span of people when lost or degraded. Soil degradation is one of the major causes of hunger and poverty and can be defined as the decline of physical, chemical and biological properties of soil. Soil degradation causes 23 hectares of land to be lost every minute (12 million hectares each year) (Anonymous, 2019). Drought, desertification, depletion of forests, soil erosion, non-agricultural uses of land and soil salinization are the main factors of soil degradation.

Salinity and sodicity problems occur in almost 75 countries around the world and their extent is increasing steadily due to improper management practices and inadequate infrastructure (Qadir et al., 2007). According to FAO (2017), approximately 19.5% of total irrigated land (230 million ha) in worldwide is affected by various degrees of salinity. Saline, sodic and saline-sodic soils constitute almost 5.5% (1.5 million ha) of agricultural areas in Turkey (Dinc et al., 2013). Increase in the world population leads to severe environmental quality concerns, such as intensive use of land and hence its degradation (Acir & Günal, 2020). In order to meet the food needs of the increasing world population and to ensure sustainable agriculture, the existing agricultural lands should be used consciously and the soils that have lost their agricultural potential should be improved.

Reclamation of saline, sodic, and saline-sodic soils can be done using physical methods, chemical methods, biological methods, hydrotechnical method, electro-reclamation method and synergistic approach (Zia-ur-Rehman et al., 2017). The traditional in-situ remediation of sodic and saline-sodic soils is accomplished through the incorporation of gypsum ($CaSO_4.2H_2O$) and subsequent leaching with freshwater irrigation. The amount of gypsum to be applied varies depending on the chemical properties of the soil and the desired rate of replacement. The extent to which the reaction goes to completion is determined by the interaction of several factors such as the differences in the replacement energies of calcium and sodium, the exchangeable sodium percentage, and the total concentration of the soil solution (USSL, 1954). Gypsum is a slow dissolving reclamation material that requires a large amount of leaching water, such as about 2.5 g l^{-1} to completely dissolve (Overstreet et al., 1951; Bhargava, 1989). When the rate of soil infiltration increases, calcium does not have enough time to replace the sodium and leaches with leaching water (Keren & O'Connor, 1982). Therefore, the reaction period between gypsum and exchangeable sodium should be extended to such an extent that these materials would go to entirely completion.

Hydrogels are products of cross-linked polymers that are insoluble in aqueous media and shows swelling behavior. Application of hydrogel to highly permeable soil, such as sandy or loamy sandy soils, provides benefits such as; maintaining moisture in the plant root zone, providing controlled fertilizer release (slow release) and improving soil physical properties (Abedi-Koupai et al., 2008). Ng & Aiken (2010) investigated the potential of using hydrogels encapsulated with water-soluble calcium salt ($Ca(NO_3)_2$) for the remediation and management of sodic soil and concluded that HEMA-co-NVP (1:1) encapsulated with a soluble calcium salt can be used to deliver Ca^{2+} to soils and thus may be used for the amelioration of sodicity in soils. Therefore, the usability of hydrogel in saline-sodic soil reclamation should be studied.

This study was carried out to investigate the usability of hydrogel in increasing the efficiency of gypsum applied to saline-sodic soils. Results obtained from this study are hoped to contribute to the development of different concepts and principles in the reclamation and management of saline-sodic soils.

2. MATERIALS AND METHODS

A disturbed soil column study was performed under laboratory conditions with a relative humidity of 60±5% and an average temperature of 25±2°C. The experimental soil was classified as Typic Natrargid according to Soil Survey Staff (2014) and was collected from 0 to 20 cm depth of the Igdir plain, located in the northeast part of Turkey. The soil has 45.6% clay, 42.2% silt, and 12.2% sand with pH in saturation extract (pH_e) 9.61, 39.3 dS m^{-1} electrical conductivity in saturation extract (EC_e), 1.04% organic matter, 8.87% calcium carbonate, and 74.72% exchangeable sodium percentage (ESP). The soil was air-dried and crushed to pass through a 8 mm sieve and were homogenized by thorough mixing. The experiment was set-up in a completely randomized design with six hydrogel application rates (Control, 0.05%, 0.10%, 0.15%, 0.20% and 0.25% weight/weight (*w/w*) basis) and with three replications, in initial. However, due to the clogging of pores (which inhibited leaching) in the columns where 0.20% and 0.25% hydrogel was applied, these subjects were removed from the research. The results of the research were evaluated considering four hydrogel application rates, as Control, 0.05%, 0.10%, and 0.15%. In order to achieve a final ESP of 5%, gypsum ($CaSO_4.2H_2O$, Merck analytical reagent grade) requirement was calculated as 51.2 tons per hectare according to the formula given by Kovda (1967). PVC columns with an internal diameter of 10.6 cm and a length of 35 cm were used for the leaching experiment. The PVC columns were filled with 5 cm of sand and gravel at the bottom and soils with defined amounts of gypsum (45.14 g per column) and hydrogels (Control, 0.05%, 0.10%, 0.15%, 0.20% and 0.25%, *w/w*) were added with simultaneous tapping to achieve a uniform bulk density (1.30 g cm^3). The length of the soil on the top of the sand and gravel was 20 cm (approximately 2300 g soil per column). In order to remove any air pockets developed during the packing process, columns were subjected to wetting process from the bottom. After the saturation period, the soils were leached by maintaining a 5 cm constant head on the top of each column using a Mariotte bottle setup. The pore volume (PV) of columns was calculated as 50.94% and all columns were leached with five pore volumes of tap water (pH_w = 7.90, electrical conductivity (EC_w) = 0.31 dS m^{-1}, and sodium adsorption ratio (SAR) = 0.26). After each pore volume of leaching, leachate samples were collected from each treatment and pH, EC, and Na^+ content of leachates were analyzed using a WTW pH/Cond 340i and Dionex ICS-3000 Ion Chromatography, respectively. Saturated hydraulic conductivity tests were performed during the last stage of leaching (in the fifth pore volume of leaching). At the end of the leaching process, all columns were allowed to drain freely. Soils from the columns were removed, air-dried and crushed to pass through a 2 mm sieve and pH_e, EC_e, and ESP content of each soil was determined.

General soil properties were determined by using the Bouyoucos hydrometer method for particle size analysis (Gee & Or, 2002), Scheibler calcimeter for $CaCO_3$ (Loeppert & Suarez, 1996), and Smith-

Weldon method for soil organic matter content (Nelson & Sommers, 1996). Exchangeable Na^+ was determined using the ammonium acetate method (Helmke & Sparks, 1996). Cation exchange capacity (CEC) was determined with a flame photometer (Jenway PFP-7, Essex, UK) using sodium acetate-ammonium acetate method according to Sumner & Miller (1996). The ESP was calculated according to USSL (1954). Soil pH_e and EC_e were determined in saturation extracts using glass electrode pH meter (Thomas, 1996) and standard EC electrode (Rhoades, 1996), respectively.

All data were subjected to one-way analysis of variance (ANOVA) procedure and the means were compared by Duncan's multiple comparison test method, performed using the SPSS Statistical Package v.20.0 (IBM, 2011) at $p<0.05$ level of significance, unless otherwise mentioned.

3. RESULTS AND DISCUSSION

Breakthrough curves for mean leachate pH and EC for different hydrogel application rates during the leaching process are presented in Figure 1 and 2, respectively.

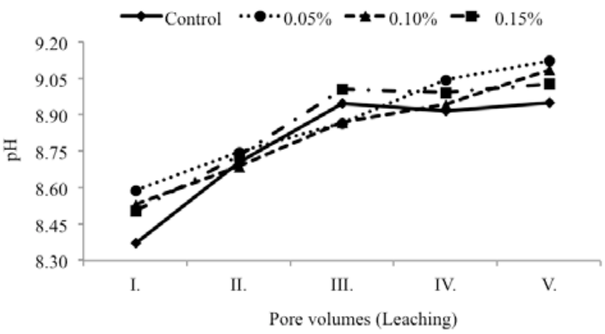

Figure 1. Mean leachate pH for different hydrogel application rates

In general, pH gradually increased with the increase of leaching water (Fig. 1). The highest leachate pH's were found after fifth pore volume (PV) of leaching. While pH of the control was found as 8.37 after first pore volume of leaching, it was found as 8.95 in the fifth pore volume of leaching. Hydrogel application to saline-sodic soil had significant effects on leachate pH. The highest leachate pH's were found in the final leachates in the order of 0.05%>0.10%>0.15%, as 9.12, 9.09, and 9.03, respectively. Increase in leachate pH can be due to an increase in negative charges resulting from concomitant specific adsorption of SO_4^{-2} and release of OH^- (Belkacem & Nys, 1997; Walia & Dick, 2019). For all hydrogel application rates tested, the highest EC values were obtained after first pore volume of leaching (Fig. 2).

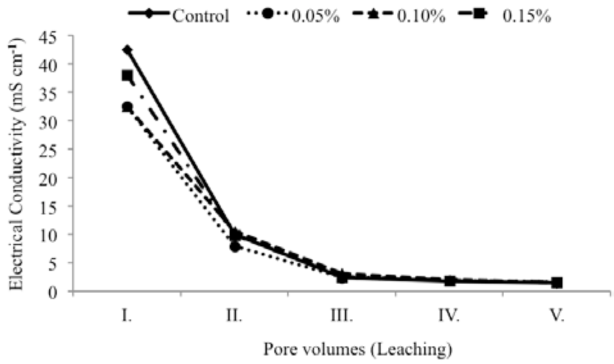

Figure 2. Mean leachate electrical conductivity (EC) for different hydrogel application rates

EC values then decreased gradually with further leaching. After third pore volume of leaching EC values have remained almost same. The reduction in leachate EC can be due to the overall removal of salts by increasing the volume of leaching water. This result is consistent with the findings of Chaganti et al., (2015) and Sadegh-Zadeh et al., (2018) who reported that leachate EC has reached to maximum amount after about one pore volume of leaching and then diminished with additional leaching. Domnariu et al., (2020) have stated that the EC values were minimum during the first stages and the last stages of nitrate leaching from undisturbed micro-lysimeters, while the maximum ones were mainly during the mid-period.

Leachate losses of Na^+ from soils amended with different hydrogel application rates are presented in Table 1. Application of gypsum to saline-sodic soil caused significant losses of Na^+. In all of the application rates tested, the highest Na^+ leachate losses were obtained after first pore volume of leaching and then decreased gradually with further leaching. Application of hydrogel along with gypsum had no significant effect on Na^+ leaching. However, the highest leachate loss of Na^+ was obtained from 0.05% hydrogel application rate. The order of leachate loss of Na^+ followed the order of 0.05%>Control>0.15%>0.10%. Relative to the control, hydrogel application in the rate of 0.05% increased the leaching of Na^+ by 8.1% on total. Results obtained suggest that application of hydrogel to saline-sodic soil is not an effective way to facilitate Na^+ loss by leaching, at high application rates. However, this study is important to show that Na^+ ions that are held in the voids of the hydrogels do not bind strongly and its swelling properties do not affect negatively at high pH values, which indicates that this material can be safely used in saline-sodic soils to reduce the risk of physiological drought.

Table 1. Leachate losses of Na^+ from soils amended with different hydrogel application rates

	Treatment	I. PV[Ψ]	II. PV	III. PV	IV. PV	V. PV	Total
Na^+ (mg)	Control	17894ab	3867	826	511	352	23450a
	0.05%	20147a	3253	757	636	557	25350a
	0.10%	12490c	3982	903	695	585	18655b
	0.15%	14620bc	3773	1114	660	517	20684ab
	p (<0.05)	0.007	ns*	ns	ns	ns	0.041

*ns: non-significant; Ψ: Pore volume

Results of previous study conducted by Chen et al., (2004) have shown that hydrogel amendment drastically changed the ion concentration of soil water and mean concentration of Na^+ and Cl^- was significantly decreased by hydrogel incorporation. Pourjavadi et al., (2008) and Wang et al. (2018) have indicated that swelling capacity of hydrogel increases with an increase in pH and swelling degree is minimum at pH 2.0.

Post leaching soil analysis is presented in Table 2. The effect of hydrogel application on soil pH_e, EC_e, and ESP were found to be non-significant. Relative to the control, hydrogel applications decreased soil pH_e, however this reduction was statistically non-significant. The lowest soil pH_e was obtained from 0.05% hydrogel application rate. While pH_e of the control was found as 9.16, it was found as 9.04, 9.09, and 9.12 at 0.05%, 0.10%, and 0.15% hydrogel application rates, respectively. Soil EC_e differences among various hydrogel application rates are given in Table 2.

Table 2. Post leaching soil analysis

Treatment	pH_e	EC_e (μS/cm)	ESP (%)
Control	9.16	565	22.20
0.05%	9.04	553	22.44
0.10%	9.09	536	21.66
0.15%	9.12	532	21.85
p (<0.05)	ns*	ns	ns

*ns: non-significant

As seen from Table 2, increase in hydrogel application rates decreased soil EC_e. However, reduction in soil EC_e among various treatments was found non-significant. The order of decrease in soil EC_e followed the order of 0.15%>0.10%>0.05%>Control. Same results were obtained for ESP. Reductions in soil pH_e, EC_e, and ESP can be due to leaching of sodium salts (Table 1). Due to the absence of statistically significant effects of the treatments on Na^+ leaching, an improvement in soil ESP and pH_e values as an indicator of reclamation was not proven. This situation indicates the necessity for reconsidering the amount of gypsum applied. The calculation for the actual amount of gypsum is difficult because of various side factors such as soil texture, surface area and type of clay and minerals. The amount of free sodium carbonate and bicarbonates found in alkaline soils reduce the displacement rates of Na^+ and Ca^{2+}. Therefore, the amount of gypsum applied should be multiplied by the factor 1.25 to compensate for the lack of quantitative replacement (USSL, 1954). The effects of hydrogel applications on the saturated hydraulic conductivity are presented in Figure 3.

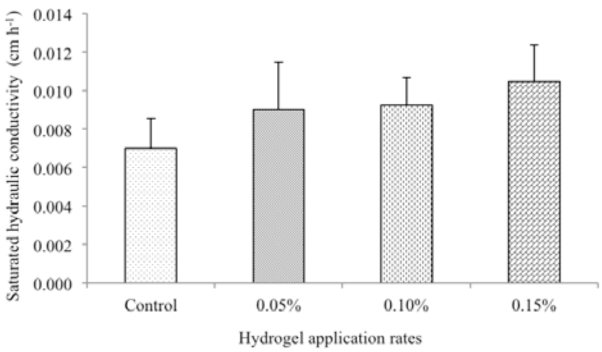

Figure 3. Effects of hydrogel application on the saturated hydraulic conductivity

In general, increase in hydrogel application rates increased saturated hydraulic conductivity. While saturated hydraulic conductivity of the control was found as 0.007 cm h^{-1}, it was found as 0.009, 0.009, and 0.010 cm h^{-1} at 0.05%, 0.10%, and 0.15% hydrogel application rates, respectively. Application of hydrogel increased saturated hydraulic conductivity in the rates of 28.6%-42.6%. Increase in saturated hydraulic conductivity can be due to an increase in the porosity and decrease in the bulk density of the soil. Uz et al., (2008), Baran et al. (2015), and Kumar et al., (2018) have reported that hydrogel application caused an increase in soil porosity and a decrease in bulk density. This result is especially important to show that the amount of time to reclaim saline-sodic soils can be reduced by application of hydrogel.

4. CONCLUSIONS

This study is the first to evaluate the usability of hydrogel in increasing the efficiency of gypsum applied to saline-sodic soils. Results obtained have shown that application of hydrogel along with gypsum had no significant effect on soil pH_e, EC_e, and ESP. However, this study is important to show that Na^+ ions that are held in the voids of the hydrogels do not bind strongly and its swelling properties do not affect negatively at high pH values, which indicates that this material can be safely used in saline-sodic soils to reduce the risk of physiological drought. Use of gypsum together with hydrogel increased saturated hydraulic conductivity of the disturbed soils, which is especially important for reducing the duration for amelioration of saline-sodic soils. Application of hydrogel to saline-sodic soils along with gypsum can be an efficient management option not only for reducing the risk of physiological drought, but also for reducing the amount of time to reclaim saline-sodic soils. The further objective of this study is not only to test the usability of hydrogel in increasing the efficiency of gypsum in field conditions but also to investigate its effects on soil physical properties.

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